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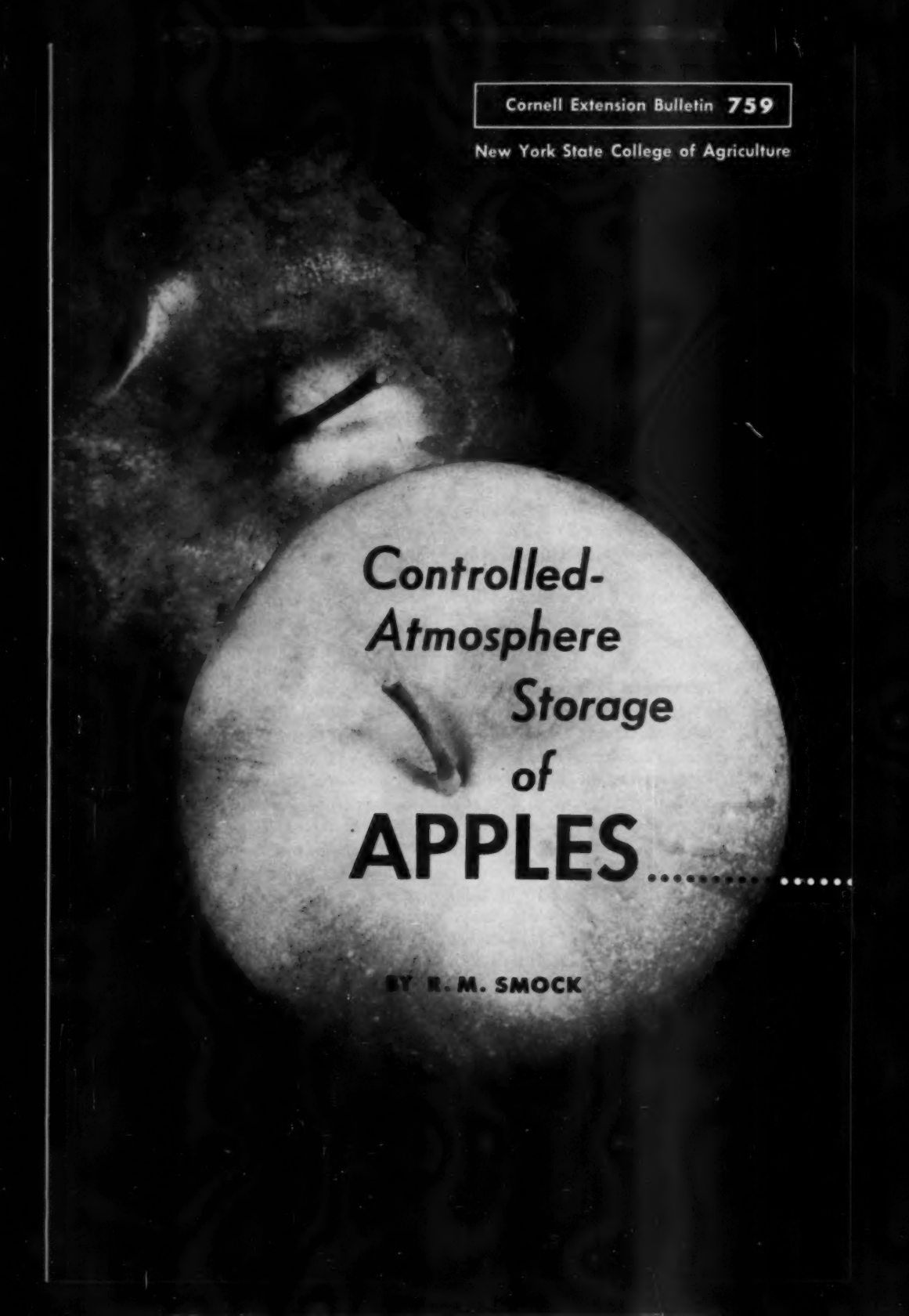

Controlled-Atmosphere Storage of APPLES

BY R. M. SMOCK

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Cover illustration: These two apples were stored for six months and then held for five weeks at 70°F. The one in the foreground was stored in controlled atmosphere. The other was kept in regular storage.

CONTROLLED-ATMOSPHERE STORAGE OF APPLES

R. M. Smock

Ordinarily, New York apples can be held satisfactorily for rather long periods in the usual type of cold storage in air. In certain instances, however, cold storage alone has not proved entirely adequate. For example, McIntosh apples cannot be held in ordinary cold storage with full assurance that they will be of prime quality after February. McIntosh apples removed from ordinary cold storage in February and March may look all right upon removal from storage, but their shelf life in a store may be very short. In addition, this variety often develops a cold storage disorder known as *brown core* when held for extended periods in cold storage at 32°F. Controlled-atmosphere storage will add considerable shelf life after February and March, even for varieties such as Delicious and Rome Beauty, which are usually considered good keepers

What Is Controlled-Atmosphere Storage?

Fruits, even though detached from the tree, are living. Like all other living things, they carry on a process called respiration. In respiration, fruit sugars are oxidized, or burned, in the presence of oxygen (O_2) in the air. As a result of the process, carbon dioxide (CO_2), water vapor, and heat are produced. The more rapid the rate of respiration, the more quickly the fruits will deteriorate. The rate of respiration, or fruit ripening, may be retarded in several ways. One of these is to lower the temperature. This is the fundamental principle of cold storage. A second way is to lower the amount of oxygen around the fruit, since this gas is required in respiration. A third is to increase the amount of carbon dioxide around the fruit. A combination of all three of these principles is involved in controlled-atmosphere storage.

Just how may the atmosphere be controlled in such a storage? A gastight room is the first requirement. The room is, of course, refrigerated to give a low storage temperature. Immediately after this gastight room is filled with apples and the door sealed, the atmosphere is air, which is composed of about 78 per cent nitrogen, 20.8 per cent oxygen, 0.03 per cent carbon dioxide, and small percentages of other inert gases. Very shortly the atmosphere in the room changes because of

fruit respiration. The oxygen level is slowly reduced by the process of respiration. The oxygen percentage finally reaches zero unless provision is made to supply some fresh air from the outside. If this complete lack of oxygen persists over a period of several days, the fruit suffocates for lack of oxygen and becomes alcoholic and badly off flavor. Hence, twice daily gas analyses are made. When the oxygen level drops slightly below that desired, fresh outside air is introduced into the room. All the while this is going on, the carbon dioxide level is increasing because it is a product of respiration. Ventilation can be used to regulate the atmosphere only when the desired oxygen and carbon dioxide levels total 21 per cent (for example, 10 per cent carbon dioxide and 11 per cent oxygen). No attention is paid to the nitrogen-gas fraction since this takes care of itself. If the atmosphere that is to be maintained does not total 21 per cent (for example, 5 per cent carbon dioxide and 3 per cent oxygen), then an extra step must be taken. Judging from what was said previously, if the oxygen level is to be 3 per cent, it would follow that there will be 21 minus 3, or 18 per cent carbon dioxide present. Since only 5 per cent carbon dioxide is needed, the excesses of carbon dioxide over 5 per cent must be removed in an atmospheric washer employing caustic-soda solution. The oxygen level, in this case, can be maintained by introducing the necessary amount of fresh air. To illustrate the situation, suppose that on a given day the gas analysis in the room reveals 6 per

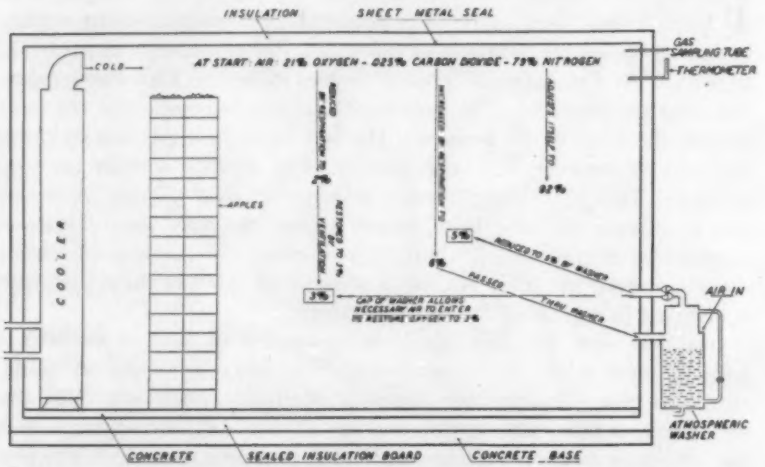

Figure 1. Diagrammatic representation of a controlled-atmosphere room indicating how the atmosphere is controlled.

cent carbon dioxide and 2.5 per cent oxygen. The caustic-soda washer is started to reduce the carbon dioxide to 5 per cent, and enough air is introduced into the room to bring the oxygen level up to 3 per cent.

What happens in a controlled-atmosphere storage is illustrated diagrammatically in figure 1.

Varietal Requirements and Responses

Not all varieties respond equally well to controlled-atmosphere storage. Some even respond adversely. Furthermore, not all varieties have the same atmospheric and temperature requirements in this type of storage.

Table 1 gives the recommendations for the proper temperature and atmospheric requirements of different New York varieties in controlled-atmosphere storage.

Table 1. Atmospheric and temperature requirements for controlled atmosphere storage

Variety	Carbon dioxide	Oxygen	Temperature
	per cent	*per cent*	
McIntosh	2–3 one month then 5	3	38 F.
Delicious	2–3	3	32
Golden Delicious	2–3	3	32
Rome Beauty	2–3	3	32
Northern Spy	8	3	38
Stayman Winesap	5	3	32
Baldwin	2–3	3	32
Jonathan	3	3	32
Macoun	5	3	38

McIntosh

The storage life of this rather soft variety can be remarkably lengthened by using controlled-atmosphere storage. Figure 2 shows the differences in firmness lost in storage, according to the pressure tester, between apples in controlled-atmosphere storage and in 32°F air. The actual difference in the firmness of apples removed from controlled-atmosphere storage and regular storage is not always very large. The biggest difference shows up in *shelf life*. It will be noted in figure 2 that McIntosh from controlled-atmosphere storage remained marketable about three

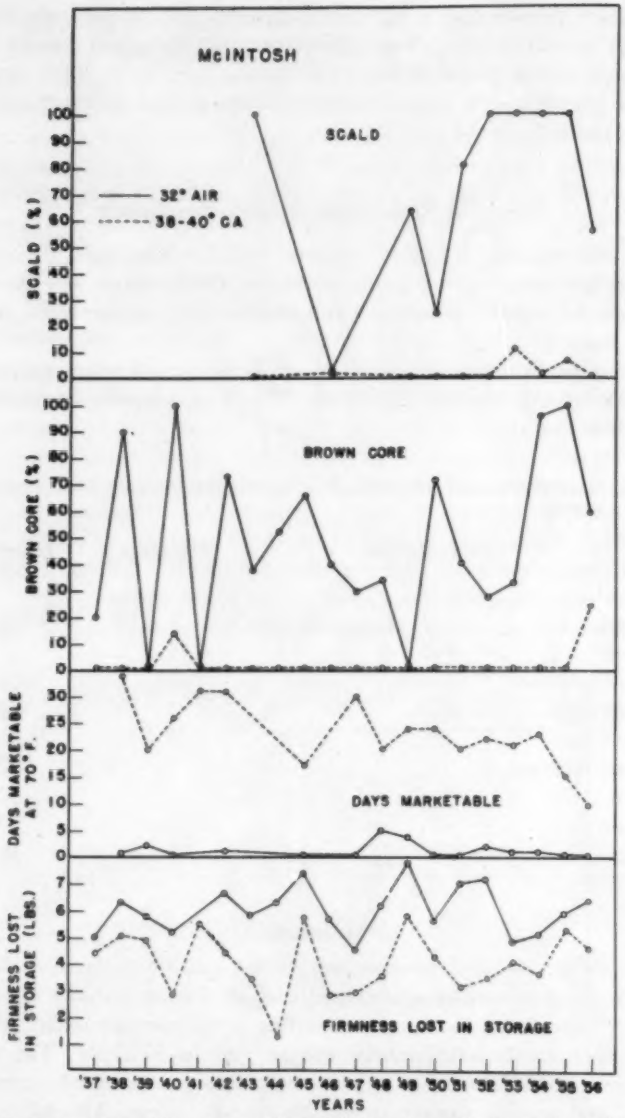

Figure 2. Comparison of keeping quality of McIntosh apples in regular cold storage (32°F. air) and controlled-atmosphere storage (5 per cent carbon dioxide and 3 per cent oxygen at 38–40°F.) over a period of twenty years.

weeks at 70°F upon removal from storage in April or May. (The only unrealistic feature of this comparison is that the apples were kept from shrivelling by keeping them in a moist atmosphere at 70°F). Similar McIntosh apples from regular storage at 32°F were marketable only about one day, on the average. Except for two years, the McIntosh from controlled-atmosphere storage were free from brown core, while brown core in apples from regular storage ranged from 0 to 100 per cent over the years. Figure 2 also indicates that controlled-atmosphere storage also greatly reduced the scald on McIntosh.

The oxygen level to be maintained is three per cent (see table 1). This variety in small scale tests can tolerate 2 per cent oxygen, but actual experience has shown that we need a "safety factor" on the oxygen level because of possible faulty air distribution.

McIntosh apples are subject to injury from high levels of carbon dioxide. Injury from carbon dioxide is pictured in figure 7. For this reason it is suggested that only 2–3 per cent carbon dioxide be maintained the first month of storage and then be allowed to rise to 5 per cent.

During the early years of our trials, 40°F was used as the temperature. It was later found that 38°F gave better results. If the temperature is too low, there may be excessive brown heart, brown core, or even failure to ripen properly. Trials were made in which the temperature was dropped two degrees each month in storage until it reached 32°F. This was found to be dangerous.

During the loading and unloading period, the temperature of a McIntosh room should be 32°F.

Delicious

Delicious is a high quality variety that sometimes becomes mealy in regular storage. Figure 3 shows that Delicious from controlled-atmosphere storage lost somewhat less in firmness than regular storage apples. Shelf life is increased by controlled-atmosphere storage but not as remarkably as with McIntosh. Figure 3 shows that the average shelf life of Delicious stored in controlled atmosphere was about two weeks, whereas the shelf life of regular storage fruit was about 3 days. Figure 4 shows firmness tests on Delicious apples from the 1953–54 season when held at 68°F. The apples were held until they reached 11.0 pounds pressure test, when they were considered too mealy for eating. Note that the apples held in 2 per cent carbon dioxide actually kept better than those held in 5 per cent carbon dioxide. This was true in certain years because of sensitivity to high carbon dioxide levels.

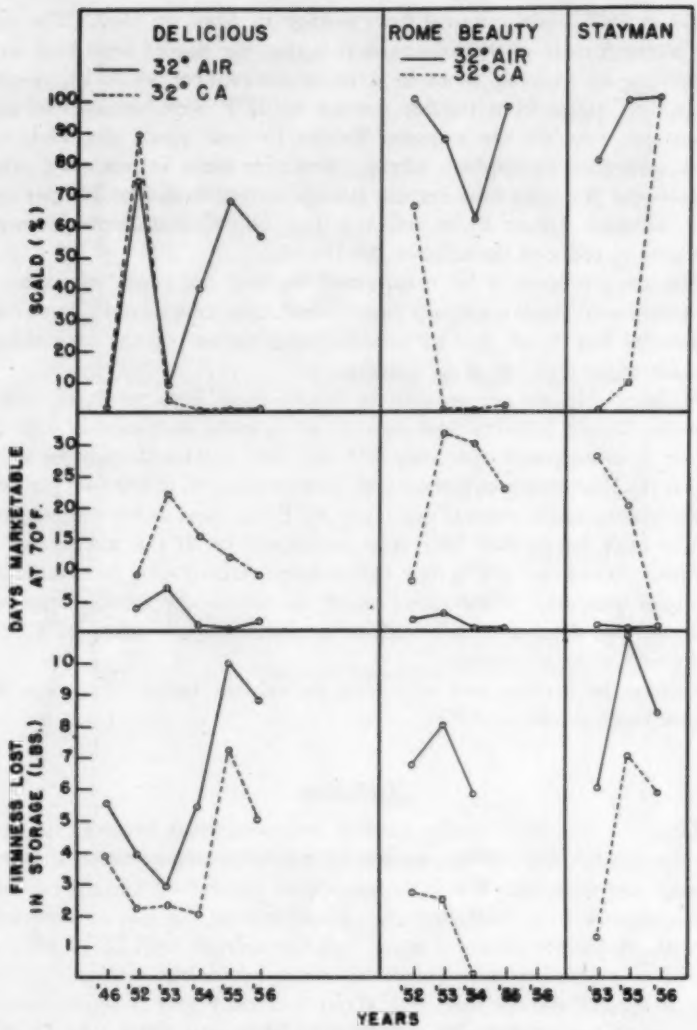

Figure 3. Comparison of keeping quality of Delicious, Rome Beauty and Stayman apples in regular cold storage and controlled-atmosphere storage. In controlled-atmosphere storage, 3 per cent oxygen was used in all cases; with Delicious and Rome Beauty, 2 per cent carbon dioxide; and with Stayman, 5 per cent carbon dioxide was used.

Golden Delicious

Golden Delicious are picked when rather mature to get the full golden color desired. It has been shown that controlled-atmosphere storage will maintain firmness better and give longer shelf life than regular storage (see figure 5). A wide range of atmospheres and temperatures has not been tried with this variety. Since it stores well with 2 per cent carbon dioxide and 3 per cent oxygen at 32°F, it can be stored in the same room with Delicious or Rome Beauty.

Rome Beauty

Rome Beauty is a hard variety that normally keeps very well in cold storage except for the hazard of apple scald disease. Figure 3 shows that CA storage greatly reduced, but did not always control, scald. Controlled-atmosphere storage increased shelf life also. Since this variety is rather subject to carbon dioxide injury, the carbon dioxide should not be allowed to go over 3 per cent. In certain years flesh injury characterized by pockets of dead, brown cells near the core has resulted from even 5 per cent carbon dioxide.

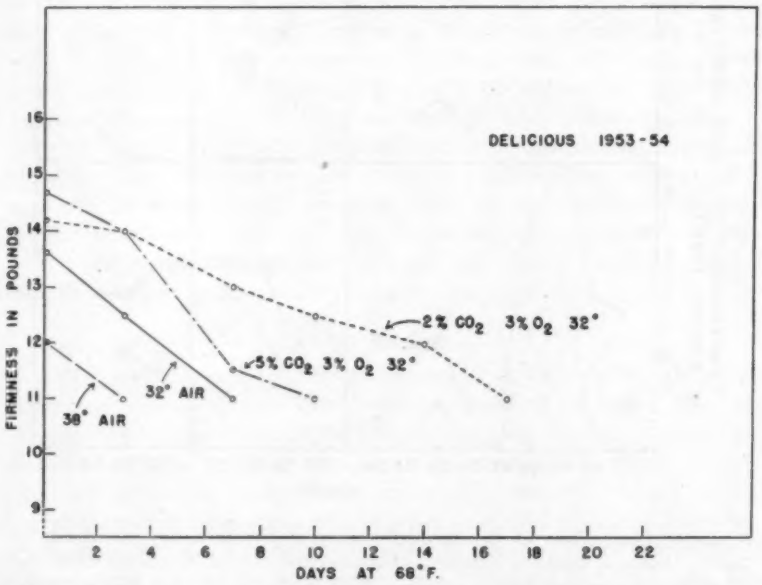

Figure 4. Firmness changes in Delicious apples after removal from storage in May. Apples held at 68°F.

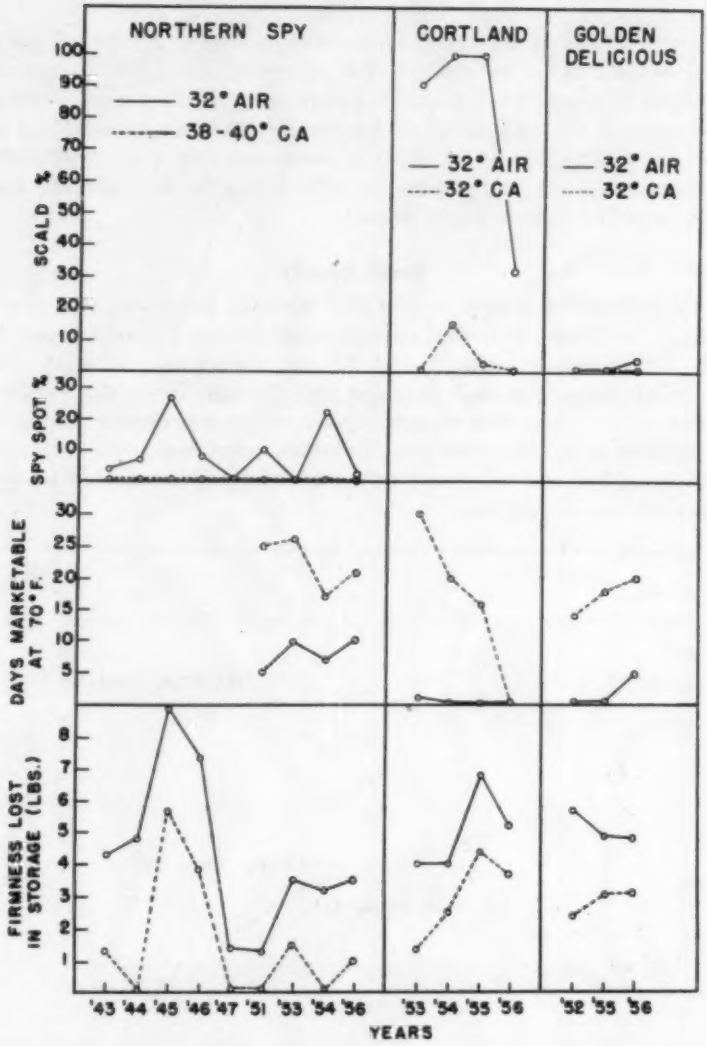

Figure 5. Comparison of the keeping quality of Northern Spy, Cortland, and Golden Delicious apples in regular cold storage and controlled-atmosphere storage, 3 per cent oxygen was used in all cases. With Northern Spy, 5–8 per cent carbon dioxide; with Cortland, 5 per cent carbon dioxide; and with Golden Delicious, 2 per cent carbon dioxide was used.

Northern Spy

Northern Spy normally keeps well in ordinary cold storage, but in certain years it develops an internal breakdown late in the season. Controlled-atmosphere storage controls this breakdown. Spy is also subject to "Spy spot" disease which is similar to Jonathan spot. Controlled-atmosphere storage entirely prevents this disease (see figure 5). Controlled-atmosphere storage keeps the apples firmer in storage and gives a somewhat longer shelf life.

In some years, storage under low oxygen atmospheres at 32°F gives remarkable storage life, but in other years, brown heart has occurred at 32°F. At present, 8 per cent carbon dioxide with 3 per cent oxygen at 38°F is the only safe recommendation. During the loading and unloading period, a temperature of 32°F is used.

Cortland

Only four years data on Cortland are presented (figure 5), since prior to 1953, a temperature of 38° or 40°F was employed. Up until that time Cortland looked unpromising in controlled-atmosphere storage because of the high incidence of scald. At 32°F with 5 per cent carbon dioxide and 3 per cent oxygen, scald seems to be greatly reduced. In certain years it may not be safe to store in controlled-atmosphere storage unless special precautions are taken against scald before storage. Controlled-atmosphere storage greatly lengthens shelf life and makes it possible to store this variety up into May if scald and carbon dioxide injury are not problems. The variety is subject to carbon dioxide injury even at 32°F, with the injury to the skin resembling that on McIntosh. High carbon dioxide injury and scald may limit the commercial application of controlled-atmosphere storage to Cortland. In 1956–57 internal carbon dioxide injury with a 5 per cent level spoiled the fruit.

Other Varieties

Only several years of trial have been made on Baldwin, Rhode Island Greening, Twenty Ounce, Northwestern Greening, Macoun, Stayman Winesap and Jonathan. Rhode Island Greening is subject to carbon dioxide injury to the flesh, but controlled-atmosphere storage reduces scald and keeps the apples firmer than regular storage. Twenty Ounce is very subject to breakdown and brown core in cold storage. Controlled-atmosphere storage will delay the onset of these troubles but will not control them. Northwestern Greening is very subject to brown core and scald in regular storage. Controlled-atmosphere storage greatly reduces or controls these troubles and gives added shelf life. Macoun can have

its shelf life considerably extended by controlled-atmosphere storage. Jonathan is very subject to Jonathan spot in storage. Controlled-atmosphere storage entirely prevents this trouble. Of these varieties, commercial trials would seem safe at present on Macoun, Jonathan, Baldwin, and Stayman Winesap (figure 3).

Fruit Disorders in Controlled-Atmosphere Storage

Scald

The intensity of scald on apples held in controlled-atmosphere storage is dependent upon the following factors:

1. *The variety:* Varieties which normally scald badly in regular storage can scald in controlled-atmosphere storage. For example, Cortland and Rome Beauty may show scald upon removal from controlled-atmosphere storage to warm temperatures.

2. *The season:* Scald intensity varies a great deal from season to season. For example, scald on McIntosh apples in controlled-atmosphere storage during the 1955–56 season was very severe. The following year it was very light. When temperatures during the latter part of the growing season are cool, scald susceptibility seems to be lessened.

3. *The rate of oxygen drop and oxygen level:* If a low oxygen level (3 to 5 per cent) is maintained in the controlled-atmosphere room and if the oxygen drops to that level rather rapidly (i.e. 10–16 days) scald is much less than in a "high oxygen" (11 per cent) room or in regular storage. In general, it can be stated that scald should be less in a well-operated controlled-atmosphere room than in regular storage (see figures 2, 3 and 5). In a study of McIntosh apples from 17 orchards during the 1955–56 season, there was one-third the scald in controlled-atmosphere storage that there was in regular storage.

4. *Scald prevention measures:* Air purification with activated coconut shell carbon, in New York studies, has been found to reduce the scald in some seasons. In a season of severe scald, air purification does not accomplish much control of scald.

Oiled paper wraps or shredded oiled paper will reduce the scald, but will not always control it. Certain chemicals will control scald but their use must be approved by Food and Drug Administration.

5. *Fruit maturity:* In general, the less ripe the fruit when placed in storage, the more severe is the scald. With McIntosh the more mature fruit are sometimes more susceptible to scald.

6. *Delayed storage:* The more promptly McIntosh apples are placed in

storage and cooled down, the less will be the scald. See figure 6. The effect of delayed storage on other varieties in controlled-atmosphere storage has not been studied as yet.

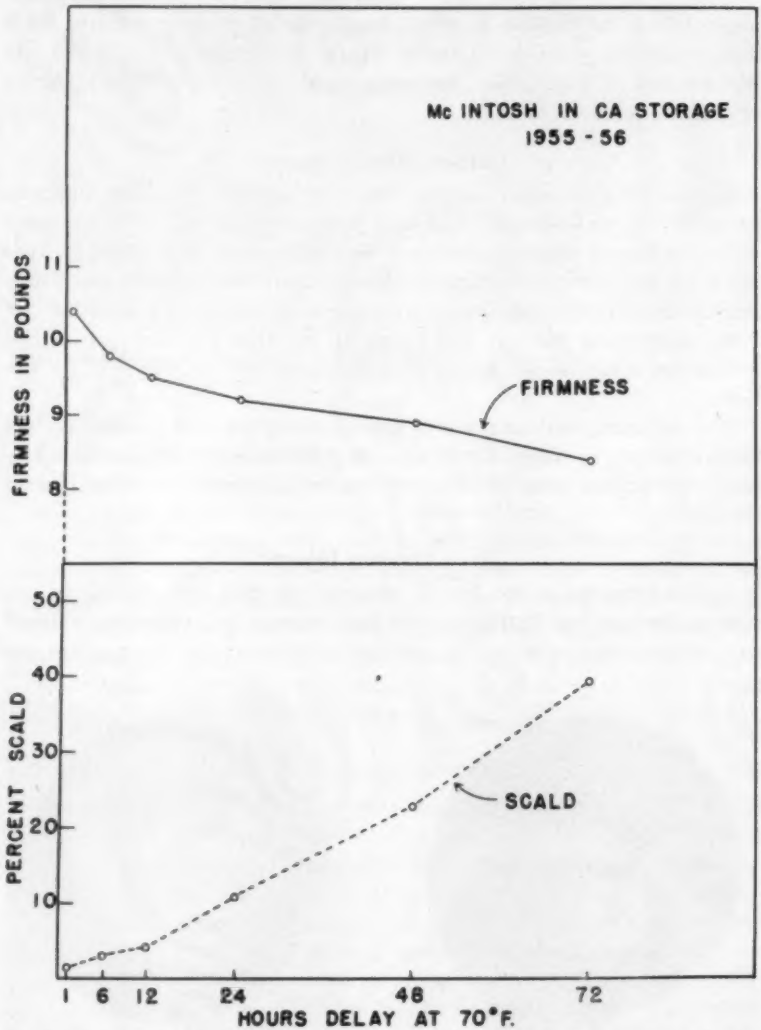

Figure 6. Effect of various periods of delay before controlled-atmosphere storage on firmness and scald in May after storage.

7. *Length of storage:* Scald tends to get worse late in the storage season. A pail of very green, prime quality, and ripe apples should be hung just inside the inspection porthole in the door. Beginning about February 1, take small samples of fruit into a warm room and look for scald development. When the samples begin to show scald after being warmed for 5 days, watch for scald development on the better apples very closely. At the first sign of slight scald, the room should be opened and the apples sold as quickly as possible.

Carbon Dioxide Injury

Carbon dioxide injury exhibits itself in different ways on different varieties. On McIntosh and Cortland it shows up as wrinkled, depressed yellow or brown areas on the green side of the fruit (see figure 7). It is worse on immature fruit. Carbon dioxide injury on varieties like Rome Beauty and Wealthy shows up as pockets of brown, dry areas in the flesh usually near the core (see figure 8). In other varieties such as Delicious the injury shows up as increased mealiness or "dryness" of the flesh.

The recommendations given in table 1 are given with possible carbon dioxide injury in mind. In seasons of great susceptibility, some injury may show up in spite of following the recommended levels of carbon dioxide.

Low Oxygen Injury

Apples subjected to too low an oxygen level may show injury. In one case an operator lost 30,000 boxes of fruit because the oxygen was allowed to approach zero on several occasions. In another case there was a loss

Figure 7. External carbon dioxide injury to McIntosh.

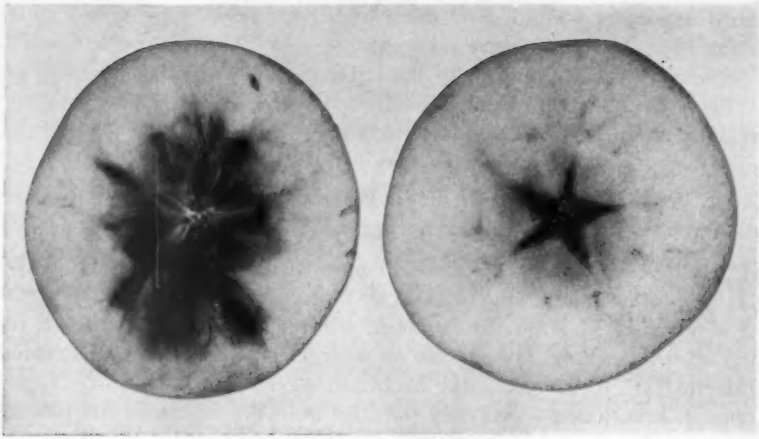

Figure 8. Carbon dioxide injury to flesh of fruit.
Left: injured Wealthy apple. *Right:* normal Wealthy apple

even though the average level was 3 per cent. In this instance the oxygen was allowed to go below one per cent on 18 different occasions.

Low oxygen injury shows up in a number of ways. On some of the red varieties like McIntosh, there may be discoloration of the skin with a purpling or browning on the red side. In some cases there are brown depressed areas resembling soft scald on the red side of the fruit. In extreme cases there is abnormal softening and even splitting of the fruit. Off flavors are usually characteristic of low oxygen injured fruit.

Low oxygen injury can be prevented by not allowing the oxygen level to go below 2.5 per cent and having good air distribution in the room.

Other Storage Disorders

McIntosh apples in some seasons develop a wrinkled browning or blackening on the red side of the fruit. This trouble may develop in regular storage but is worse in controlled-atmosphere storage. The cause of this "X" disease is as yet unknown.

Decay may develop on fruits with punctures in controlled-atmosphere storage, but decay does not develop as rapidly as in regular storage.

Bitter pit on varieties like Northern Spy does not develop as rapidly in controlled-atmosphere storage as in regular storage. Controlled-atmosphere storage does not control the trouble. Low temperature disorders such as brown core, soft scald, soggy breakdown, and internal

browning can be avoided by using higher temperatures (38–40°F) and using controlled-atmosphere storage.

Storage scab will continue to develop in controlled-atmosphere storage.

Fruit shrivel is a problem in controlled-atmosphere storage only if the relative humidity is allowed to drop below 90 per cent.

Handling Fruit Prior to Storage

Maturity

For best results, apples stored in controlled atmosphere storage should be picked at the right time. Fruit picked too soon lacks quality and is very subject to scald. Fruit picked too late will be too ripe when removed from storage. For a guide on when to pick, see Cornell Extension Bulletin 750. In a variety like McIntosh where proper maturity is very critical, it may mean that only the fruit from the middle of the picking season should be put in controlled-atmosphere storage.

Prompt Storage

The ideal situation is to have fruit put in controlled-atmosphere storage the same day that it is picked. It certainly should be in storage within 24 hours after picking. Delayed storage increases scald on McIntosh and the fruit does not come out of storage as firm as it might have had it been stored promptly, (see figure 6).

Careful Handling

All varieties must be handled carefully, but this is especially true of a variety like McIntosh. Rough handling results in excessive decay and gives the fruit an unattractive appearance.

Grade of Fruit

Apples come out of controlled-atmosphere storage no better than they went in. "One cannot make a silk purse out of a sow's ear." Only high grade and high quality fruit promptly stored will justify the extra expense of controlled-atmosphere storage. Storage of field run fruit can be justified only when the average grade of the fruit is U.S.#1 or better.

Filling the Room

Time Required

The room should be filled and closed within 10–14 days after the first fruit is brought into the room. Waiting a month before sealing the room loses much of the advantage of controlled-atmosphere storage.

Closing after 7 days is better than closing after 14 days, yet it is important that the apples are cooled down properly before the room is sealed. It would be possible to fill a room in three days, but this would mean overloading the cooling capacity of most rooms, and sealing a room of "hot fruit" is not good, even though it means a very rapid oxygen drop.

Stacking

One of the common mistakes in operating controlled-atmosphere rooms is improper stacking. Properly designed duct work must be used to distribute the atmosphere to all parts of the room. Fruit must not be stacked in front of duct outlets. There must be four-six inches of air space at the side walls. With a duct running the length of the room, crates may be stacked against the end walls. Moving atmosphere should pass at least one side of each container. Air must be allowed to return to the blower. With hand stacking, this means leaving a space of 4–6 inches at the center of the room to act as a return duct. Crates can be stacked directly on the floor unless flooding of the floor from overflowing of the brine sprayer cooling unit is a problem. When apples are stored on pallets or are placed in storage with a clamp-type truck, air distribution is not a big problem. The pallets leave space for air movement, though not past every box. To introduce the clamps of a clamp-type truck, spaces must be left to use the clamps. With hand stacking or clamp-type truck stacking with New England boxes, it is preferable to stack so that the boxes are parallel with the walls so that air can get from the wall space to the center air space.

Filling

It is extremely important to have the room full of fruit. A room only three-fourths full should not be operated as a controlled-atmosphere room. A full room gives a faster oxygen drop and gives a bigger "pay load."

Mixing Varieties

Certain varieties can be stored in the same room. A study of table 1 will show which varieties have the same requirements. McIntosh are somewhat in a class by themselves. Northern Spy have about the same storage requirements but are picked a month or more later than McIntosh. Macoun could be stored with McIntosh. It is not uncommon to see the following varieties in the same room; Delicious, Golden Delicious, Rome Beauty, and Stayman Winesap. Others that could be

combined with the last mentioned varieties would be Jonathan and Baldwin. If Delicious and Stayman Winesap are stored in the same room, however, the carbon dioxide level should not be above that recommended for Delicious. In other words, in making a combination always use the lowest carbon dioxide value recommended for any one variety.

Packing Before or After Storage

Whether fruit should be stored field run or graded before storage depends in large part on the preferences of the owner of the fruit. The objection to storing field run fruit is that storage charges are made on cull or low grade fruit. Somewhat less bruising is experienced on apples when they are packed before storage. In some years McIntosh must be hand sorted and sized after storage. The main advantage to packing after storage is that a "fresh pack" free from decay and other defects can be sold. The trade increasingly wants a fresh pack late in the season. Another advantage is that sometimes the apples are sold after storage as field run. Still another advantage is that grading and packing before storage takes time and the fruit can be put into storage more promptly when it is stored field run.

Containers

No special containers are required. Field crates and standard wooden boxes are used. In a few instances apples packed in a specially made carton have been stored in controlled-atmosphere storage. Such cartons must be well ventilated and well spaced to get proper cooling.

Operating Temperatures and Relative Humidity During Loading

With all varieties the temperature of the room should be 30–32°F during the loading period to remove field heat as rapidly as possible. With varieties such as McIntosh and Northern Spy, the temperature is allowed to rise to 38°F after the door is sealed.

It is extremely important to keep the relative humidity as high as possible during loading, because the cooling coils are extracting a great deal of water from the air at this time. Furthermore, the box wood is usually quite dry. It is important to have the container wood absorb as much water as possible before sealing. On field-run fruit this can be done by wetting down each day's loading with water from a hose. Water atomizers can be used during the night after each day's loading to help bring the relative humidity up. The relative humidity should be *at least* 85 per cent during loading.

Construction of the Controlled Atmosphere Room

Size

THERE is no given "best size" for a room. Rooms range in size from 1500 boxes to 20,000 boxes in size. There is no theoretical reason why a room could not hold 100,000 boxes. There are certain practical aspects that determine the size of the room, however. Can the room be filled and sealed in 10 days? How many apples does the operator want to sell in a 4–6 week period upon opening in the late winter or spring? A small operator might want one 5,000 box room. However, many New York operators have two to six rooms which hold 10–12,000 boxes each. One room would be opened March 1, one April 1, etc.

Insulation

In general, the insulation requirements are no different than for regular storage, (see Cornell Extension Bulletin 786). There is one important difference, however. Controlled-atmosphere storage requires a **perfect vapor seal** be placed on the outside of the insulation. In putting on an inner gas seal, we placed a vapor seal just where it should not be from the standpoint of water vapor penetration. A number of controlled-atmosphere rooms with ground cork or board cork have been shown to have wet insulation and rotten timbers simply because a perfect vapor seal was not installed. This perfect outside vapor seal should be an "envelope" around the entire room.

Making the Room Gastight

The controlled-atmosphere room must be gastight or it will not operate properly. There are many ways to make a room gastight and more ways are constantly being found. Since these methods change rapidly, the prospective operator should determine what the latest satisfactory method is.

Floor sealing is a must and the method is fairly standard. Two layers of 55 pound asphalt impregnated roofing paper are hot mopped in hot asphalt on the subfloor under the insulation. The layers are laid down so that the joints do not lie directly under one another. Another method is to use roofers' felt (2–3 layers) and make a typical "built-up roof" on the subfloor with hot asphalt. The wall seal must tie in with this floor seal. This means that the wall metal must be flashed into the floor seal and fastened into it with hot asphalt. The wall metal that runs behind the concrete floor should be protected with a coating of hot asphalt to check corrosion from the wet concrete.

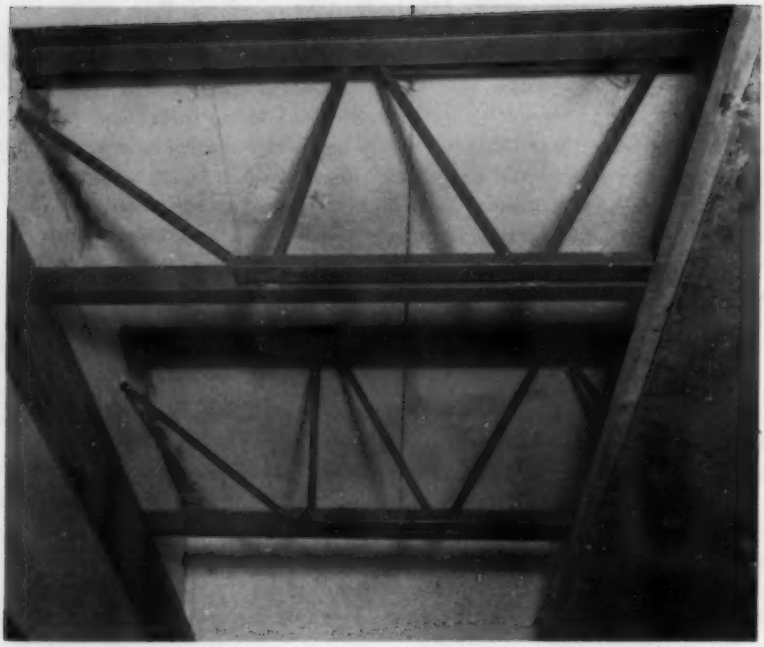

Figure 9. One method of fastening metal to ceiling. Metal sheets are fastened to 2" x 4" lumber bolted to underside of bar joists. In this case, there is sandwich-type construction of insulation on top of the bar joists.

The walls and ceiling are usually made gastight with 28 gauge galvanized iron sheets (see figure 9). Aluminum sheets are very subject to corrosion. A high grade, gun grade caulking compound that will not dry out is used to seal the joints. The sheets may be overlapped or butted. If they are overlapped two inches, caulking is laid down under the first sheet before it is fastened on the wooden grounds. Then another bead of caulking is laid down on the top of the first sheet at the edge where an overlap will be made. The second sheet is fastened down with large-headed, galvanized nails every two-three inches. The caulking that oozes out is smoothed down over the overlap and all nail heads are covered with caulking compound. If the sheets are butted, a space of 1/8th to 1/4th inch is left between sheets. It is preferable to caulk under the sheets before they are fastened down. Then a galvanized sheet metal molding is slightly overfilled with caulking compound and is screwed

with galvanized screws every 6–8 inches. The caulking that oozes out is smoothed down over the joint between the molding and the metal sheet to give a good seal.

The metal sheets are fastened to wood. If ground cork insulation has been used, the metal is fastened to the rough lumber that is the confining wall for the cork. Sometimes the metal itself confines the ground cork; in which case the metal is fastened to the upright joists.

In some cases board type insulation materials are used. In this instance, wooden grounds (1″ x 3″) are fastened to the insulation with hot asphalt. The wooden grounds are flush with the surface of the insulation. The board insulation is first "routed" out to accommodate the wooden members. See figures 10, 11 and 12. It is advisable to anchor these wooden members to the outside wall occasionally.

At the corners of the ceiling, welded pieces of metal are used to seal the junction of the walls and ceiling. The metal should be about 8″—10″ on all sides from the exact corner. This makes for easier sealing of the sheets.

Figure 10. Screwing down metal sheets to wooden grounds imbedded in board-type insulation. Wooden members have been fastened with hot asphalt to insulation.

Figure 11. One method of sealing butted joints of metal on wall. Galvanized metal molding filled with caulking compound screwed down on wooden grounds imbedded in board-type insulation.

Attempts have been made to make the rooms gastight without the use of metal. Aluminum foil encased in plastic film or asphalt paper has been laid up like wall paper, using a special adhesive at the joints. Some of these rooms are successful and some are not. The main problem is in getting a seal at the joints. Another problem is tearing of the material by abrasion from fruit crates and handling equipment.

Other methods of making the rooms tight are still under experimentation. One involves using tilt-up concrete walls made from very dense concrete with the concrete being vibrated into place. The first layer of board insulation is put in place in the concrete before it is tilted up and while the concrete is still wet. A special problem of sealing is presented at the joints of the wall or roof sections. Another method under observation is the use of special foam types of insulation which in themselves are gastight. The problem here is getting the joints gastight and sealing the wall-ceiling and wall-floor corners.

Figure 12. Installation of board-type insulation for controlled-atmosphere room. Metal sheets are fastened on wooden grounds imbedded in insulation.

Holes through the wall for the introduction of refrigeration pipes and electrical conduits should be kept to a minimum but two such holes are usually required. A metal sleeve should line each hole. After all the pipes are in place, board insulation is cut to roughly fit around the pipes and then the pipes are thoroughly encased in caulking compound on both faces of the holes. The inside of all electrical conduits must be sealed around the wires with caulking compound.

A quarter inch (outside diameter) copper tube should run from the test station outside the room to the inside of the room for gas analyses. This tube should run through one of the holes made for refrigeration pipes, and should draw air from a spot in the room where air distribution is good.

A metal gastight door must be fitted inside the usual insulated refrigerator door. This can be a one-piece black iron door or it can be metal sheeting over a wooden framing. The one-piece black iron doors are satisfactory if they are not buckled by overheating during the cutting and welding operations. A large hole (about 25″ x 25″) is cut in the door about 30 inches from the floor level. This is used as a window and

"escape hatch." A glass or plexi-glas window is sealed into place with caulking compound or vaseline. A ship's porthole (6″ to 8″ in diameter) is placed in the door above and to the side of the window. This is used for an inspection port and also to allow pressure to be released from the room when air is being added to the room (see figure 13).

The gastight door is fastened to a framing on the inside gastight wall. This framing can be replaceable so that it is not in the way when loading and unloading the room. The door is fastened down on knife grade caulking compound with bolts spaced every 4–6 inches. The door is sealed at the floor level with knife grade or gun grade caulking compound. It should be sealed from the inside of the room as well as the outside. This is done before the window is sealed in place.

Testing for Gastightness

After the room is finished and before fruit is put in it, it should be tested for gastightness. One person should stay in the room with a ladder or portable scaffolding and gun grade caulking compound to repair any leaks that are found. A tilted manometer draft gauge which will read to one inch of water pressure is connected with a rubber tubing to the copper gas sampling tube (see figure 14). The manometer must be level.

Figure 13. Inspecting apple condition through porthole. This port is also used to let pressure off room when air is being added.

Figure 14. Measuring the leakage rate on a controlled-atmosphere room with a pressure gauge.

A pressure blower is connected to the two-inch pipe which will later be used for introducing air. Air is blown into the room until the pressure reaches one-inch water gauge. The loss in pressure is now timed in minutes. Experience has shown that a 10,000 box capacity room should not lose all the pressure (down to zero) in less than 30 minutes. A really good room will require several hours to lose all the pressure. Figure 15 shows actual results with 37 New York rooms. The designations of "fair" and "excellent" are broad ones. A 15 minute room (15 minutes from one-inch pressure down to 0 pressure) may be a borderline room. That is, the oxygen may eventually go down to 3 per cent, but it goes down too slowly.

If leaks are present in the room, they can be heard by the man working inside the room. They can usually be repaired with gun grade caulking compound.

Smaller rooms (i.e. 2000 boxes) must be tighter than large rooms. For example, it is known that palletized 2000-box capacity rooms must give a 60 minute test to work properly.

Figure 16 shows actual results with two 10,000-box rooms. Room 1 lost all its pressure in about 12 minutes. It required a month for the oxygen to drop to 3 per cent. Room 2 was a 45 minute room and the oxygen was down to 3 per cent in 11 days.

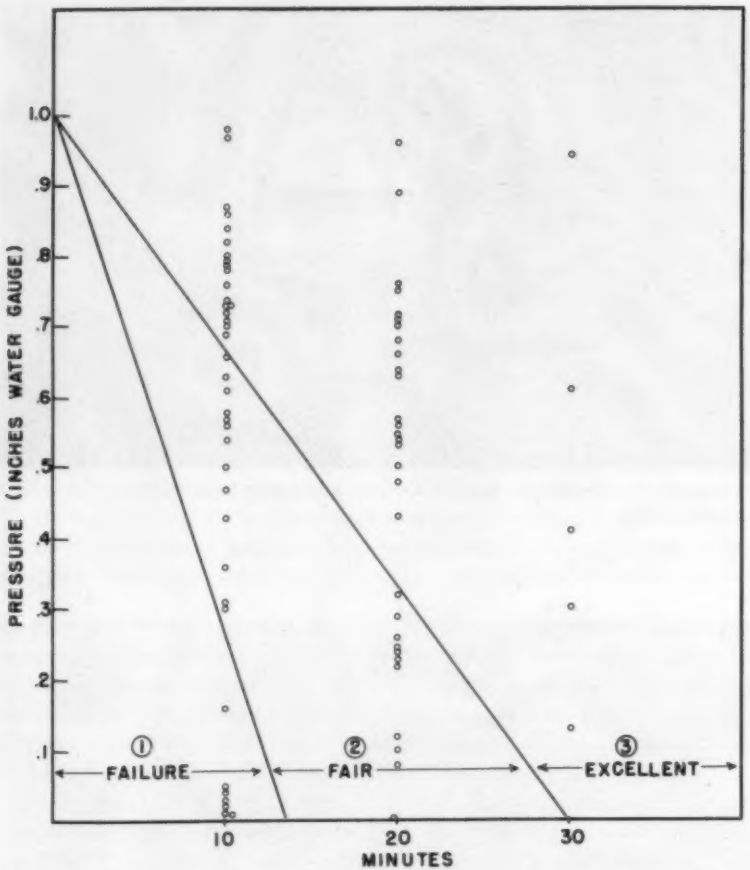

Figure 15. Performance of 37 controlled-atmosphere rooms as related to tightness as measured by loss of air pressure from 1" water gauge. "Excellent" refers to oxygen drop to 3 per cent in 9 to 14 days. "Fair" refers to oxygen drop to 3 per cent in 12 to 16 days. All rooms were of about 10,000 box capacity.

Equipment

Refrigeration Equipment

No special refrigeration equipment is required. The cooling capacity must be sufficient to remove the field heat from a specified loading rate per day to 32°F core temperature in three days. Coil surface, coil

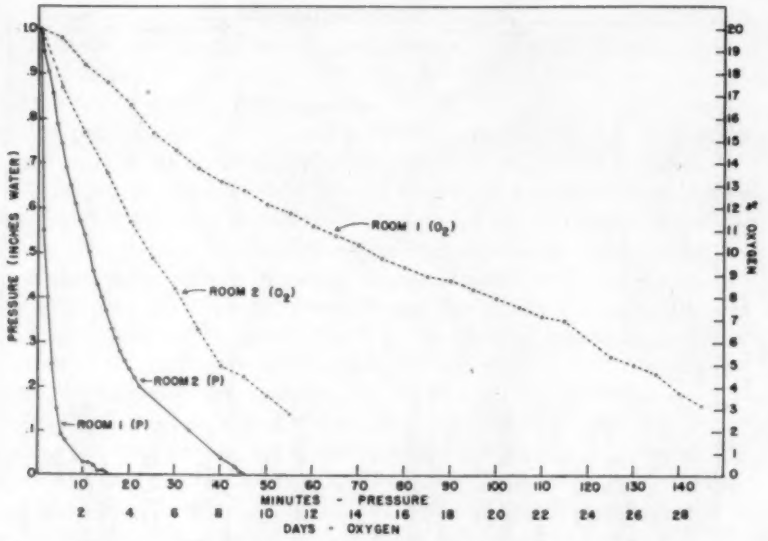

Figure 16. Actual performance of two controlled-atmosphere rooms in oxygen (O_2) drop to 3 per cent as related to pressure test (P). Room 1 was a leaky room. Room 2 operated very well.

temperature and air movement must be such that a 90–95 per cent relative humidity can be maintained during the holding period. Air movement should approximate one cubic foot of air movement per minute per box of fruit in the room. High volumes of air accomplish faster cooling rates and do not dry out the fruit if the relative humidity is very *high*. In a McIntosh room held at 38°F it is often, if not always, necessary to use a back pressure control valve on the refrigeration line to give a high coil temperature and thus a high relative humidity. Figure 17 shows the effect of back pressure, scrubbing, and the effect of refrigeration on relative humidity in a controlled-atmosphere room.

Both Freon and ammonia have been successfully used as refrigerants. However, if there were a refrigerant leak, ammonia could cause great losses whereas Freon would not.

Proper distribution of the cold air is a must. Any room over 40 feet long should have a properly balanced duct to give equal air movement from each slot opening in the duct (see Cornell Extension Bulletin 786). There should be 4–5 inches between the top of the duct and the ceiling to repair ceiling leaks.

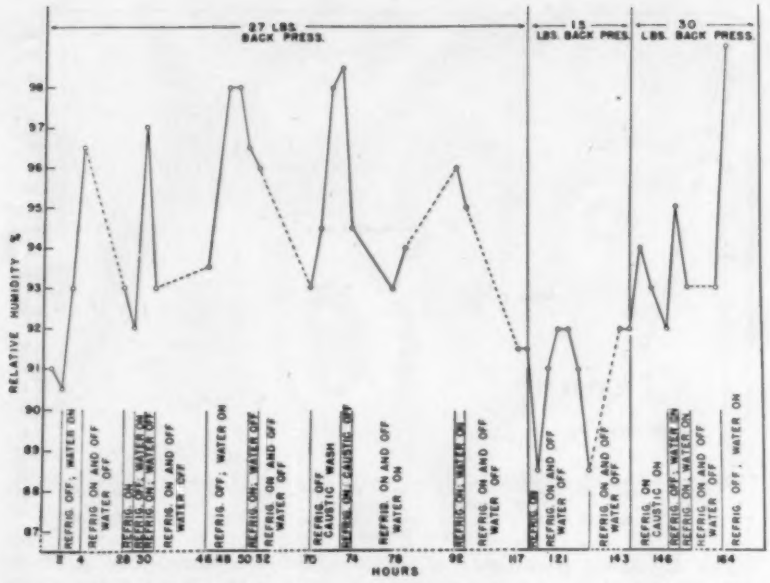

Figure 17. Relative humidity in controlled-atmosphere room as influenced by refrigerant (Freon) back pressure, whether refrigeration was on or off in coils, and whether or not "scrubbing" of atmosphere was going on.

The cold diffuser should be near the door, and stacking should be such that the fan pulley can be seen from the window in the gastight door. If for any reason the fan should stop, it should be easily detected. Cloth streamers in the air stream will indicate whether the blower is working. If a fan belt breaks or a motor burns out on the blower, it is essential to use an air mask to go into the room through the window in the gastight door and make repairs.

The cold diffusers should have "brine proof" motors. They should have bearings on the fan shaft that do not require frequent greasing. The motor should not require frequent oiling. New belts should be put on yearly.

The blower must be in continuous operation at all times.

All refrigeration controls such as thermostatic controls and back pressure regulators should be on the outside of the room for ready access.

The Atmospheric Washer

To prevent accumulations of carbon dioxide above the desired amount, it is necessary to remove part of this gas without introducing too much outside air. A washing device must be used to "scrub" the carbon dioxide out of the atmosphere until the proper amount is attained. The active agent used in the scrubber is flake caustic soda (sodium hydroxide).

There are a number of designs for scrubbers. Several designs involve having the scrubber outside the chamber. The atmosphere from the chamber is drawn up through a dripping solution of caustic soda. To give maximum contact between the atmosphere and the liquid, the tower is packed with coke, porcelain saddles, or similar materials. The washed atmosphere is returned to the chamber by means of a blower. Details on design can be had by writing the Department of Pomology at Cornell University. The advantages of an exterior type scrubber are: it is accessible for any necessary repairs; there is usually less spray drift in the room. The disadvantages are: unless large volumes of water are used in the tower type of scrubber, efficiency of scrubbing is not high; the relative humidity in the room may not be as high as can be maintained with an interior type of scrubber.

Another principle for scrubbing involves utilization of a conventional

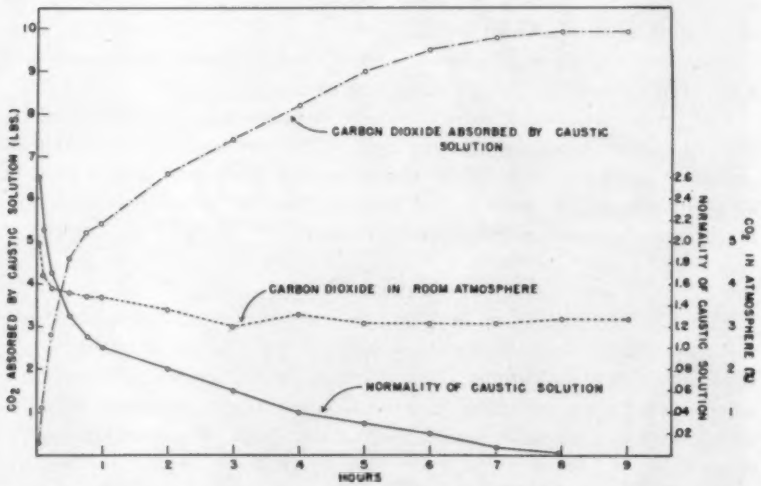
CO2 ABSORBED BY CAUSTIC SOLUTION (LBS.)
CARBON DIOXIDE ABSORBED BY CAUSTIC SOLUTION
CARBON DIOXIDE IN ROOM ATMOSPHERE
NORMALITY OF CAUSTIC SOLUTION
NORMALITY OF CAUSTIC SOLUTION
CO2 IN ATMOSPHERE %
HOURS

Figure 18. Efficiency of removal of carbon dioxide from 1400-box McIntosh room with 10 pounds of caustic soda in 120 gallons of water, using a brine spray type scrubber.

type brine spray cooling unit. The caustic soda solution is made up in a tank outside the room and is pumped to the brine spray unit. It returns to the reservoir by gravity from the brine spray unit. If such a unit is used with a holding temperature of 32°F in the controlled-atmosphere room, salt must be used with the caustic soda to prevent freezing of the liquid. Such units are very efficient in their utilization of the caustic soda. A typical efficiency curve is shown in figure 18. One pound of caustic soda will absorb approximately one pound of carbon dioxide. Water itself has some absorptive capacity for carbon dioxide. In a McIntosh room at 38°F, it was found that 115 gallons of water in a brine spray unit picked up 0.3 pounds of carbon dioxide. Salt water at 32°F has even a greater ability to absorb carbon dioxide. It was found that 115 gallons of salt water at 32°F would pick up about one pound of carbon dioxide.

Such units tend to maintain a high relative humidity in the chamber unless the coil temperature is too low. Corrosion of such units is primarily from the salt used and not from the caustic soda. Brine spray units should be made from hot-dipped galvanized iron and corrosion-resistant paint should be kept on all surfaces in contact with the salt brine. A phosphate corrosion inhibitor can be used with the salt to minimize the corrosion problem. A brine spray unit used in scrubbing may be seen in figure 19. The 125 gallon reservoir tank on the outside of the room appears in figures 20 and 21.

The spent caustic soda solution and salt water should be drained into a dry well where they cannot harm any trees.

The proper amount of caustic soda to use can only be determined by trial and error. A normal amount for a 10,000-box room would be 15–20 pounds twice a day early in the storage season. Not more than a total of 30 pounds should be used in 125 gallons of water. More than the minimum amount required should never be used.

Ventilating Blower

The usual method of replenishing the oxygen level is to blow air into the room. A two-inch iron pipe should extend into the room from the work space for air additions. This pipe may be capped with an iron plug when the fan with its flexible hose is not in use. For a permanent installation there can be a gate valve ahead of the small blower which can be shut when the blower is not in use (see figure 20).

For additions of air this blower does not have to possess much power. It should have an outlet that can conveniently be attached to the two-inch pipe mentioned above. For a permanent installation, a small blower

with a 5000 rpm motor can be used. This blower delivers sufficient air per minute to use in testing the gastightness of the room as well as to add air to the room during the holding period.

When adding air to the room, the inspection port hole must be left open (see figure 13). Only trial and error will indicate how many minutes the fan must be run each day to keep the oxygen up to 3 per cent. Some operators do not use a blower every day, but supply a "regulated leak" to the room by using different sized caps on the two-inch pipe supplying air. The pipe would be completely capped during the oxygen pull down. Through trial and error it can be

Figure 19. Air purification unit placed below brine spray type atmospheric scrubber.

Figure 20. Caustic soda being flushed into reservoir tank for scrubber. Small blower for adding air to room may be seen with shut-off valve.

found what size opening in the pipe will maintain the oxygen at 3 per cent. When using this method of adding air, it is important that the air input line not be too close to the analyzer tube. If it is close to the analyzer sampling tube, it is important to cap it completely about an hour before taking the gas samples. Otherwise, the sample may show an abnormally high oxygen level that is not typical of the rest of the room.

A Breather Bag

To accommodate sudden atmospheric pressure changes in the gastight room, a Pflug breather bag can be attached to the room. A large vinyl plastic V-shaped expansion bag or lung is suspended from the ceiling outside the room and is attached to the room by means of a four-inch pipe without elbows or bends. There are unquestioned pressure changes within the room. When the refrigeration comes on in the cooling coils, there is a "shrinking" of the atmosphere and the bag will deflate. When carbon dioxide scrubbing is started, there is a considerable reduction of volume of the atmosphere in the room. When outside barometric pressure is lower than that in the room, the bag will inflate. This bag acts as a cushion or reservoir of atmosphere. Hence, the bag will inflate at times and deflate at other times.

It is somewhat of a debatable point as to how necessary such a bag is on a really gastight room. On a room right on the borderline of gastightness, the breather bag may save the day and help bring the oxygen down to three per cent. On a really leaky room, it does no good at all. Nitrogen gas added to the breather bag increases its effectiveness but if the room is very leaky, the cost of the nitrogen gas becomes exorbitant.

Air Purification Equipment

Air purification units are standard equipment in CA rooms. Air purification involves passing the storage atmosphere through activated coconut shell carbon. Such a unit is pictured in figure 19. Ideally, it should direct the "clean" atmosphere into the intake side of the blower or cold diffuser. However, it takes up valuable space in this position and may corrode badly from salt drift. For this reason, many operators have placed it above the door of the controlled-atmosphere room.

The main function of an air purification unit is to keep down foul odors in the room. Such odors tend to accumulate in a gastight room and can affect the flavor of the fruit. However, when a brine spray "scrubber" is used, the odors do not ordinarily accumulate very much. The water and caustic soda solution pick up odors and this water is drained off once or twice a day.

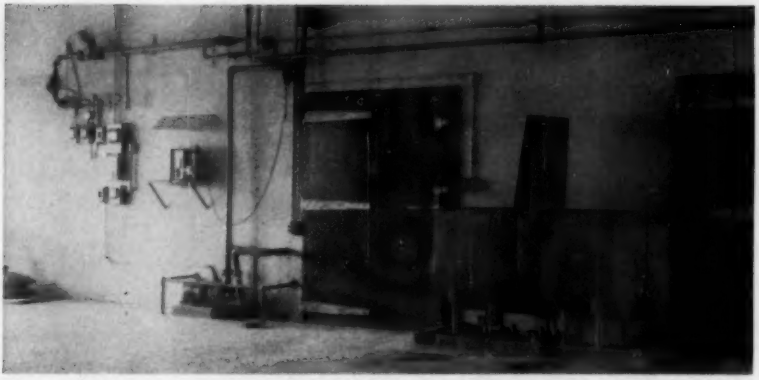

Figure 21. Gas analyzer on shelf at left of insulated door to controlled-atmosphere room. Split tank for reservoir of caustic soda solution serving two controlled-atmosphere rooms.

With a tower type scrubber utilizing a small water volume, air purification is a must for the purpose of controlling foul odors.

The other function of the air purification unit is to keep down the scald disease. In a severe scald year, it does not control scald. In a light scald year, there may be a difference of slight scald in a room with no air purification to no scald in the room with air purification. It cannot be relied upon to control scald every season.

Gas Analysis Equipment

An Orsat apparatus must be used to measure carbon dioxide and oxygen twice daily. An all-glass Orsat analyzer is likely to have fewer leaks than a metal type. See figure 22. Automatic indicators for these two gases are too expensive for the average operator.

Gas samples are taken from the gastight chamber through a 1/4-inch (outside diameter) copper tube running into the room.

An accurate log is very important in operating a controlled-atmosphere room. Below may be seen a typical log in which entries are made twice daily (i.e. early morning and evening).

Date of sealing 9/30/57

Date	Hour	Room	CO_2	$CO_2 + O_2$	O_2	Caustic added	Temp.	Air added
			%	%	%	lbs.	°F	Min.
1/3/58	7AM	2	5.5	8.3	2.8	20	38	15

Temperature and Humidity Equipment

An *accurate* thermometer should be hung in the room so that it can be seen through the window.

A wet and dry bulb relative humidity indicator should be hung so that it can be seen through the window. There should be a large reservoir of distilled water around the wick on the wet bulb thermometer. Since there is not adequate air movement past the wet bulb, the indicator tends to read about 5 per cent high.

Operation of the Controlled-Atmosphere Room

For details on actual operation and gas analyses of a controlled-atmosphere room write the Department of Pomology of Cornell University for "Handbook for Controlled Atmosphere Rooms."

Costs

Costs of controlled-atmosphere storage vary with the size of the chamber. The cost per box is much higher for a 1000-box capacity room than for a 20,000-box room. Method of construction also determines cost. Actual experience has shown that construction costs could be twice as high per box in one plant compared to another where cheaper construction was used. Costs depend in large part on how much farm labor is used in actual construction.

Detailed cost data are not available except in a very general way. For comparative purposes, one can say that if it costs $2.00 a box for a refrigerated cold storage of 10,000-box capacity it will probably cost $2.50 a box for a controlled-atmosphere storage of the same size. Operating costs are higher for controlled-atmosphere storage because of the labor involved of twice daily checking the atmosphere and changing the solutions in the scrubber. There is also the cost of extra salt and the caustic soda used. For each box of apples stored it will require about 1/4 pound of caustic soda for the season. With caustic soda costing 8 cents a pound, this would be an additional cost of 2 cents a box.

Since the storage season is longer, there is added cost for extra power consumption.

Advantages of Controlled-Atmosphere Storage

The storage life of certain varieties is markedly increased by this type of storage as compared to ordinary refrigerated storage. Apples of high quality can be sold late in the spring or early summer.

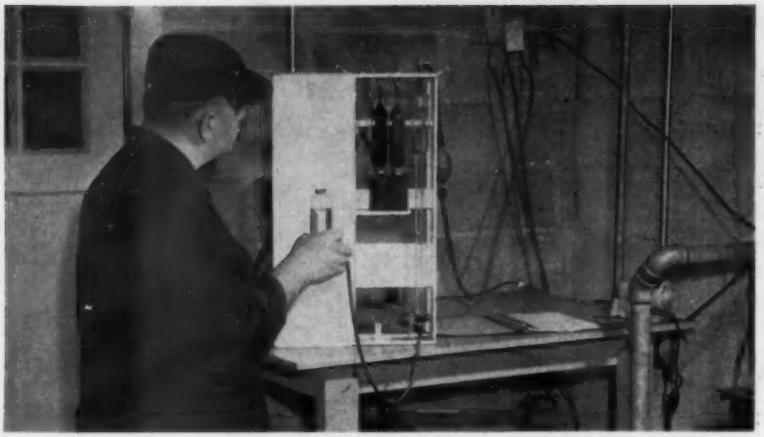

Figure 22. Analyzing the atmosphere with an Orsat-type analyzer.

Apples out of controlled-atmosphere storage have a longer shelf life. This is probably the most striking effect of this type of storage. Even McIntosh should remain marketable for a week or more in a hot store in May.

Scald is reduced in intensity. Apples can scald in controlled-atmosphere storage, but in general, it is about one-third of that on comparable apples in regular storage.

Varieties like McIntosh that are subject to low temperature disorders, such as brown core, can be stored at a higher temperature and still be firm upon removal from storage. Disorders such as Jonathan spot and Spy spot are prevented.

Mice and rats cannot live in this type of storage.

Disadvantages of Controlled-Atmosphere Storage

THE operator cannot go into the sealed room for any reason. The room is kept sealed up until it is opened to remove the apples. The operator must wear an air mask or an oxygen mask when he goes into the room to make repairs.

Not all varieties can be stored in the same room. To be in the same room, the varieties must have the same time of picking and have the same temperature and atmospheric requirements.

It is more expensive than conventional cold storage.

Storage until late in the season involves a certain speculative risk.

Precautions

1. The room must be gastight or the venture will be a failure.
2. The room must be filled with apples.
3. The fruit must be of high quality and of the proper degree of maturity to justify the added expense of this type of storage.
4. The room must be sealed up within 10–14 days after starting to fill it in the fall.
5. The proper atmospheric and temperature requirements must be followed for each variety.
6. The atmosphere must be checked twice daily.
7. The oxygen must never be allowed to go lower than 2.5 per cent. The carbon dioxide level must not be allowed to rise higher than that recommended for the variety.
8. Open port hole in the door when adding air to the room.
9. A relative humidity of 90–95 per cent must be maintained during the holding and unloading period. During the loading period it should be at least 85 per cent.
10. There must be good circulation of the atmosphere in the room. The apples must be properly stacked.
11. Never go into the room without an air mask or an oxygen mask.
12. The caustic soda solution used is harmful to the skin. It will also burn clothing. If it gets on the skin, wash it off immediately. Do not breathe the fumes of the caustic soda when making up the solution of the material with water.
13. Control odors in the room by some means.
14. Do not let the spent caustic soda or salt solutions come in contact with the roots of trees or other plants.
15. Air out the room well before removing the gastight door. Gas analyses should show 18–20 per cent oxygen before men work in the room to remove the fruit.

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